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Khwarizmi Lab

Characterizing Encrypted Application Traffic Through Cellular Radio Interface Protocol

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Encrypted network traffic *ensures* no **eavesdropping**!

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ensures no **eavesdropping**!

What if...

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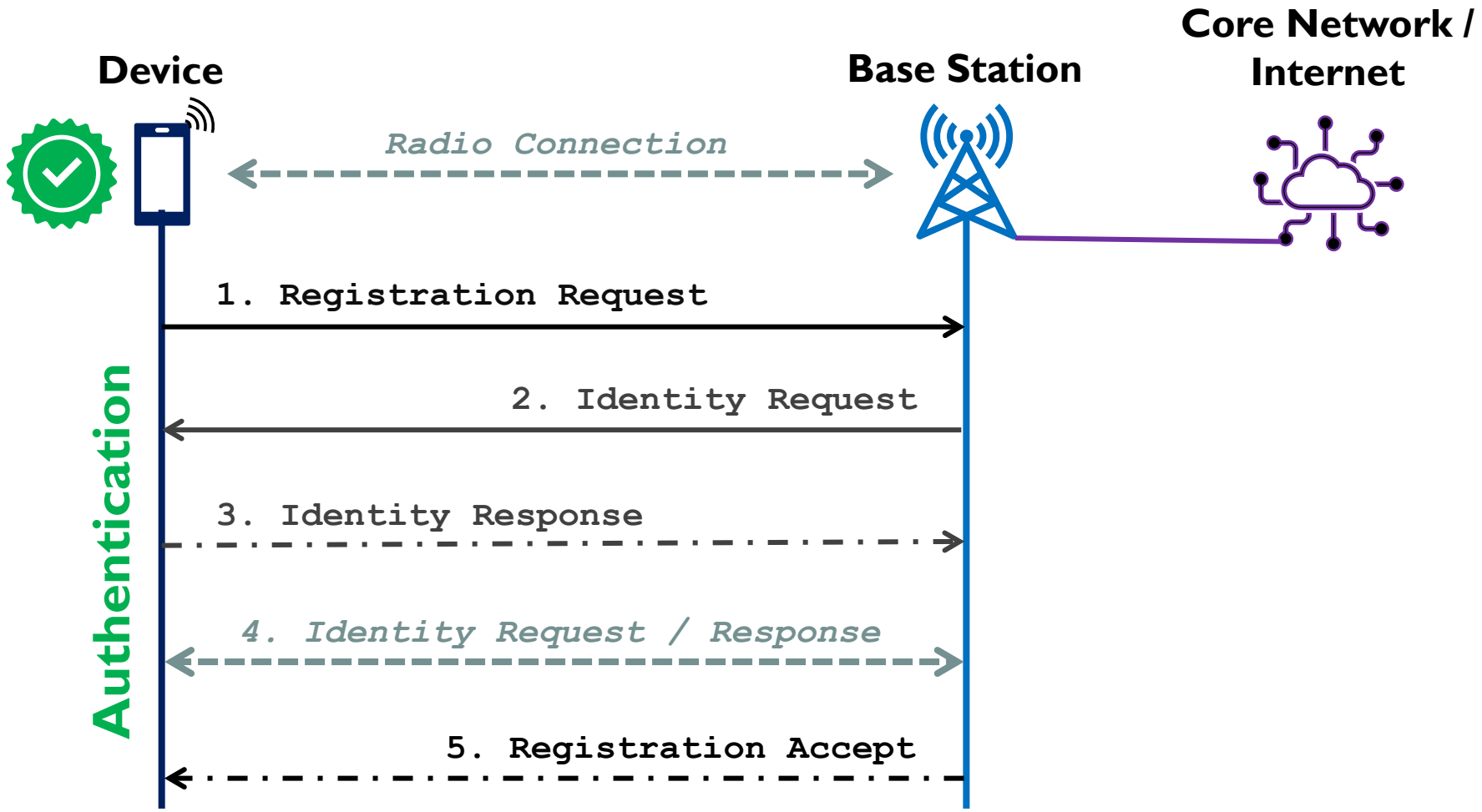
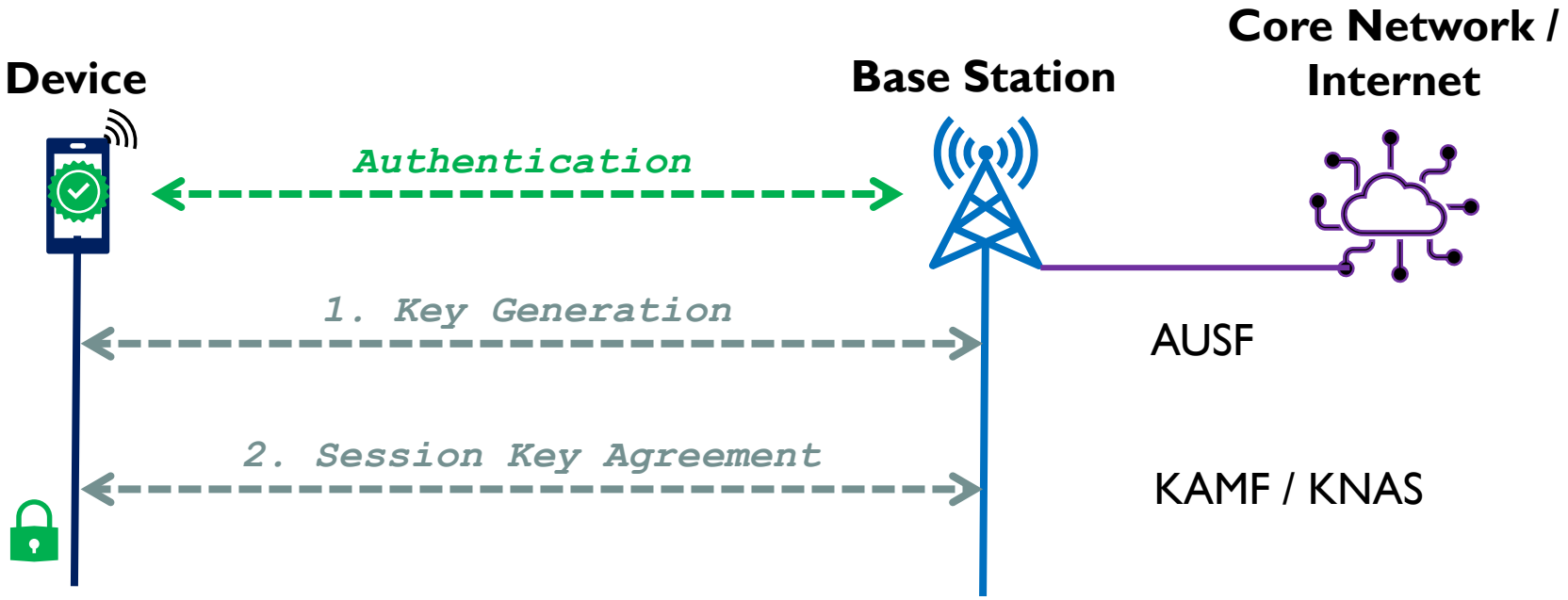
An adversary can still see what apps the user-device is using!!!

Understanding 5G: Device Registration



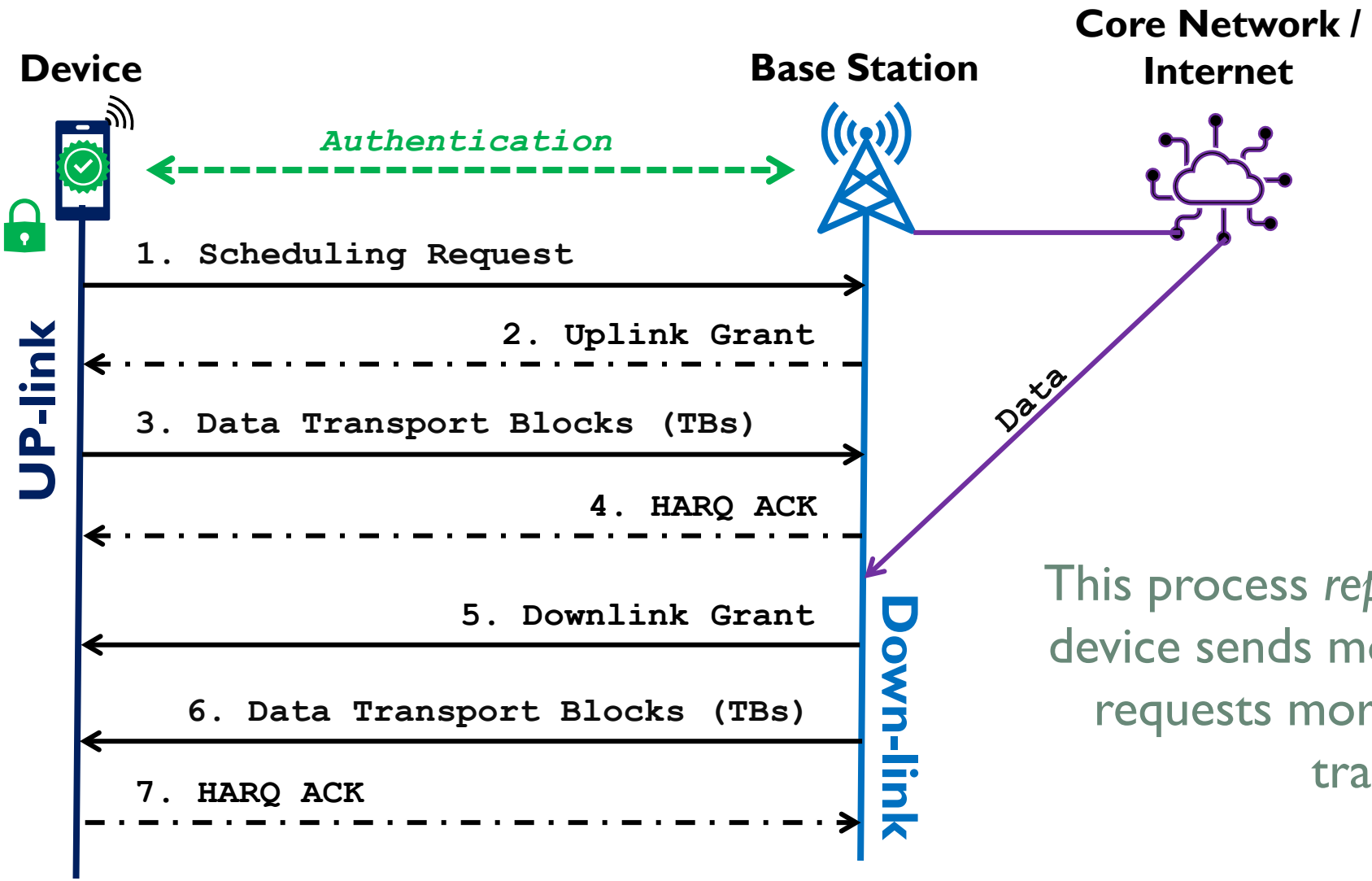
Every device needs to register and authenticate before accessing the 5G network.

Understanding 5G: Encryption Keys



The **NAS layer** encrypts all messages in subsequent exchanges, e.g., service requests, configuration updates.

Understanding 5G: Data Transmission



This process *repeats* as the device sends more data or requests more downlink transmissions.

Despite strong **authentication**, **encryption**, and **access control** mechanisms, how can an **adversary** learn about the **device's activities** over the network?

Research Question

Despite strong **authentication**, **encryption**, and **access control** mechanisms, how can an **adversary** learn about the **device's activities** over the network?

Radio Resource Blocks (RRBs) Allocation!

The Key Idea: Observing Physical and MAC layer Interactions

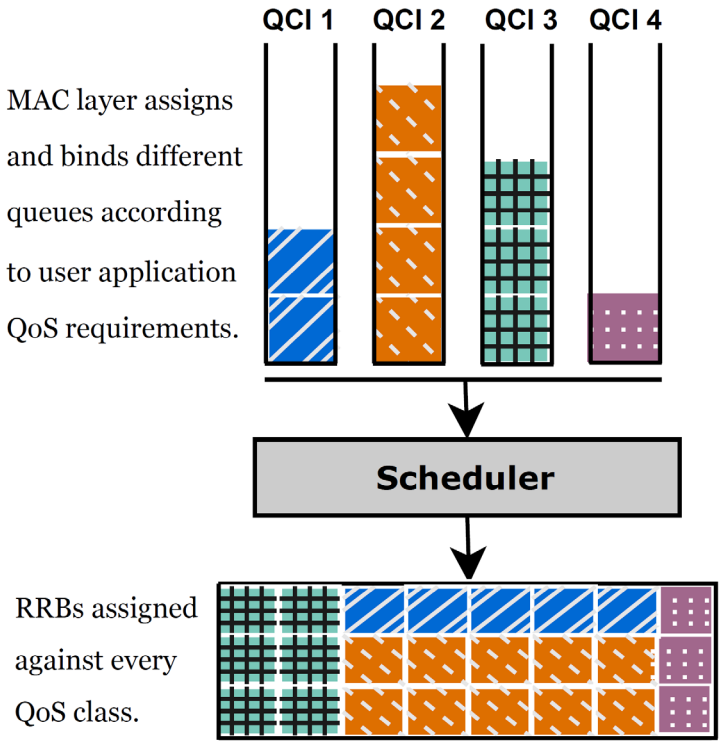
The device pushes data to the **PDCP layer**.

The **PDCP protocol** transfers the data to the **MAC layer**.

Stores the data in application-specific buffer for transmission.

The **MAC scheduler** requests the base station for radio resources:

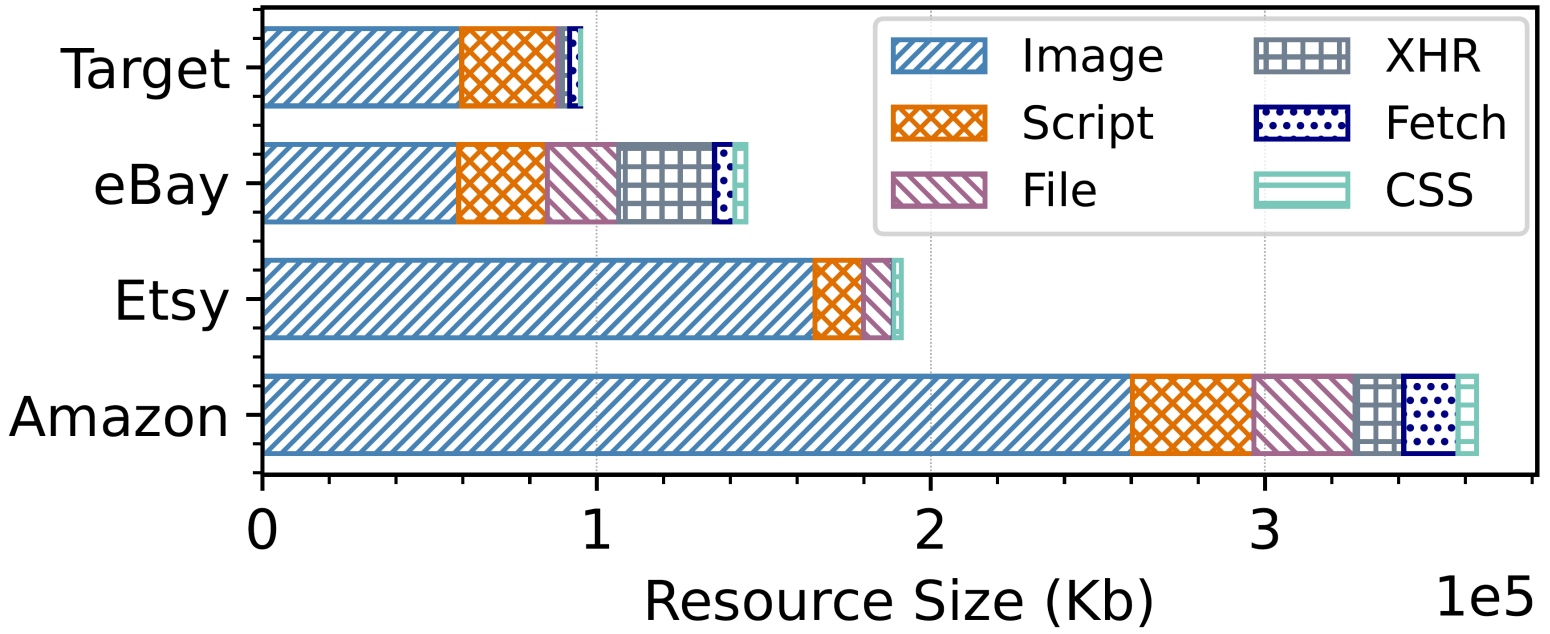
Buffer sizes	Quality-of-Service (QoS)	Priority



The device is running four different types of applications, e.g., voice call, web browsing, streaming, and real-time gaming.

MAC Scheduling

- There are 26 **QoS Class Identifiers (QCI)** indicating:
  - Guaranteed Bit Rate (GBR), or Non-GBR
  - Relative priority
- MAC layer assigns and binds different queues according to user application QoS requirements.
- The scheduler assigns RRBs against every QoS class.
  - It takes the *number*, *size*, and *priority* of different queues into account.



Key Insight: Unique Application Resources

How to acquire **scheduling** information for device-application **fingerprinting**?

Challenge 1

Acquiring Scheduling Information

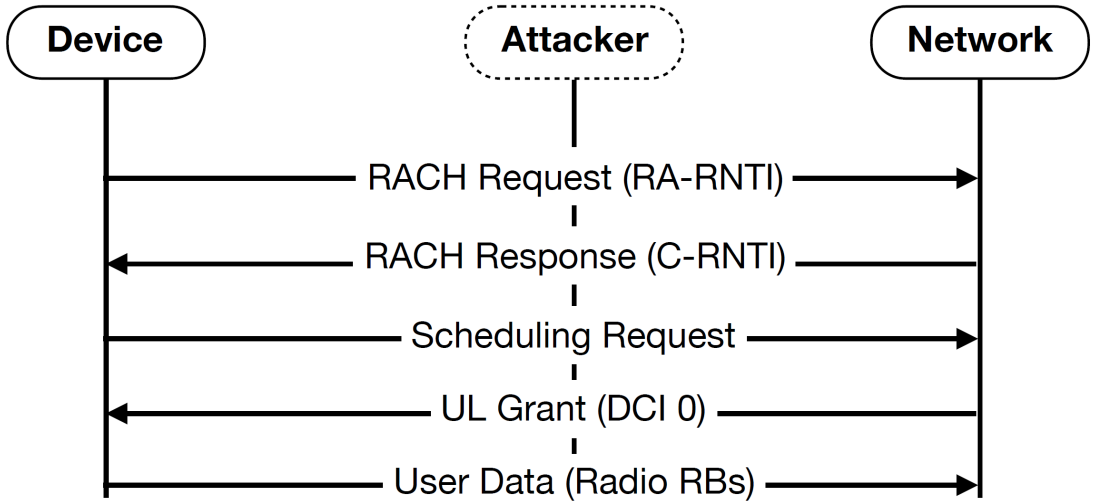
- **Downlink Control Information (DCI)** through the **Physical Downlink Control Channel (PDCCH).**
  - DCI Type 0: Uplink
  - DCI Type 1: Downlink
- Bitmap indicating the **Resource Block Groups (RBGs)** allocated to the device.
- The DCI is transmitted **without encryption** over the air.

- Eavesdrop on the **PDCCH** and retrieve the bitmap with **RBGs**.

How to identify the victim device?

Challenge 2

Identifying the Victim Device



- When a device registers with the network, it receives **C-RNTI**.
  - Unique device identifier within the cell.
  - Helps the device to identify the data intended for it.
- C-RNTI is sent in plaintext.
- The attacker can identify who is who over the radio communication.


5G
EXPERIMENTS,
EVALUATION, &
FINDINGS!

Experimental Setup

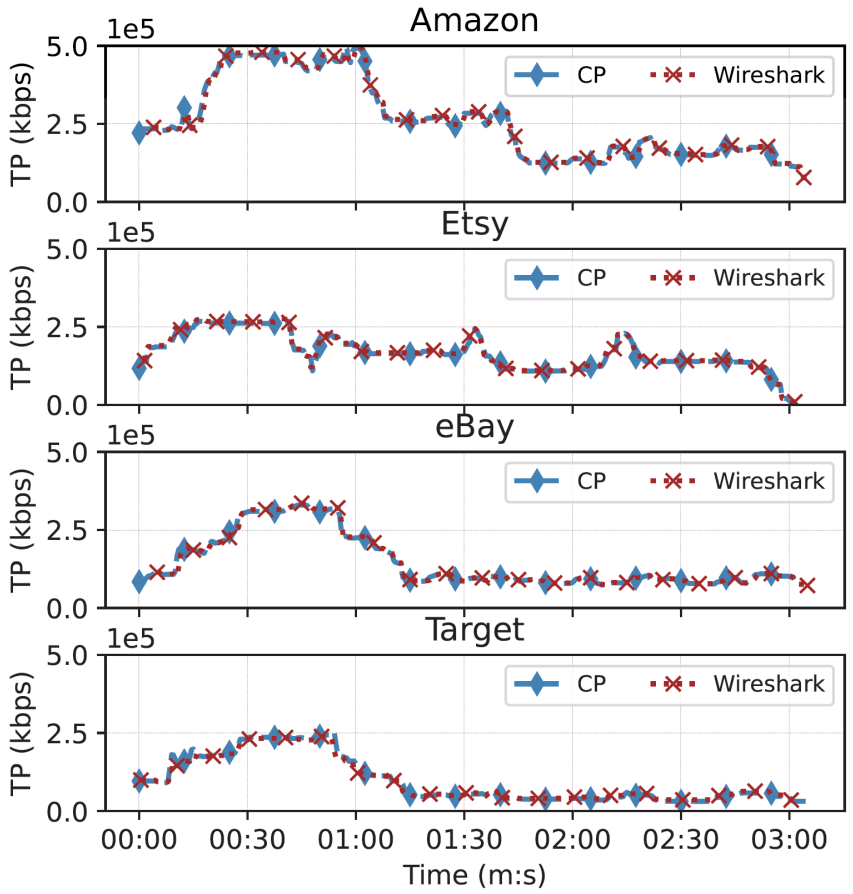
- OnePlus 5G cell phone.
  - Running multiple GBR and non-GBR applications.
  - Automated with Selendroid.
- **QXDM** and **QCAT** for collecting traces.
  - Radio Resource Block (RRB)
- We collect the traces for a single application at a time.
- 1217 traces over six-months.
  - >= 20 iterations per application.
  - 43 GBs!

Data Link

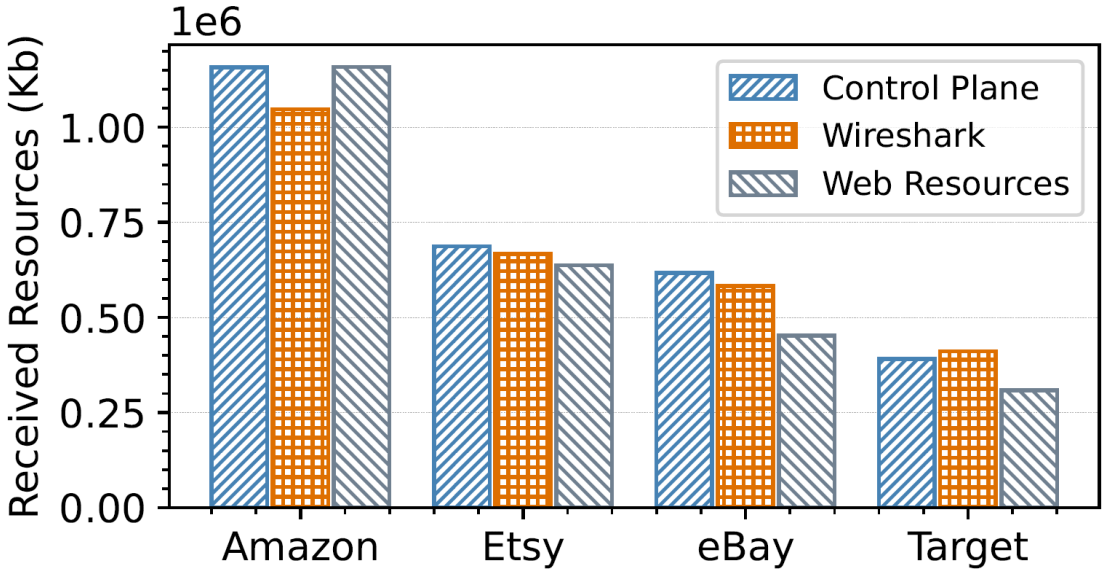
Service Category	Applications
Online Shopping	Amazon, eBay, Etsy, Target
Voice/Video Conferencing	Facebook Messenger, Telegram, WhatsApp, Zoom
Video Streaming	YouTube (Live and Non-Live in various qualities)
OTT Services	Apple TV+, Amazon Prime Video, Netflix

RRB vs. Device Wireshark

Continuous Usage

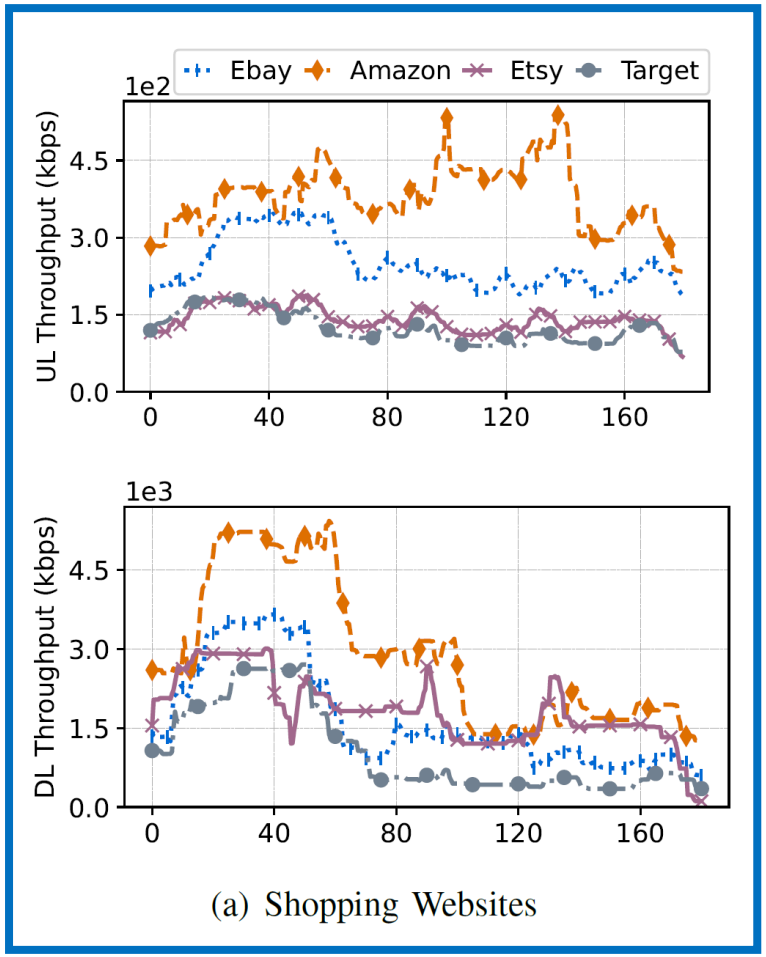


Total Usage

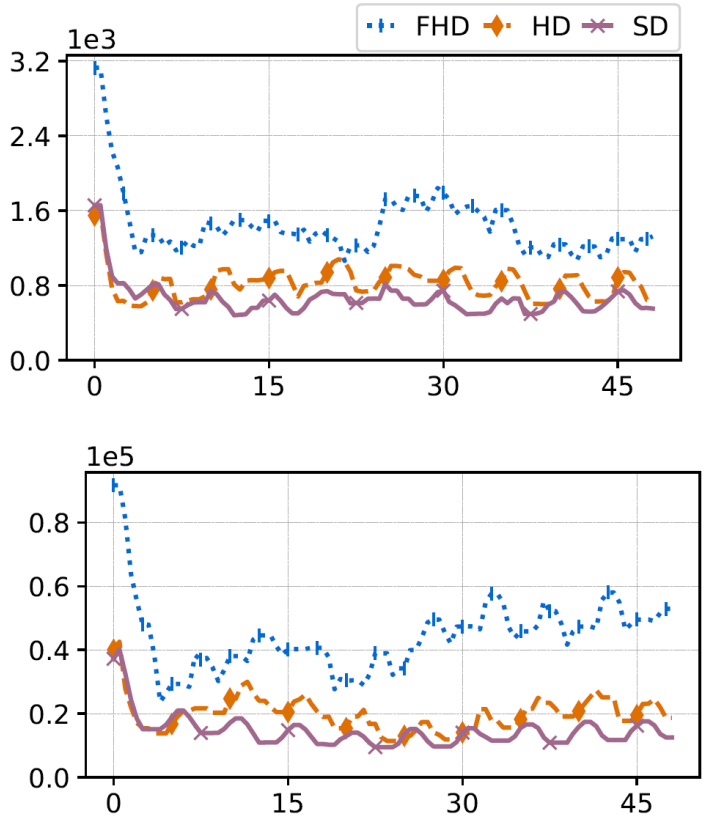


Throughput patterns in RRB and Wireshark are *identical* and *interchangeable*.

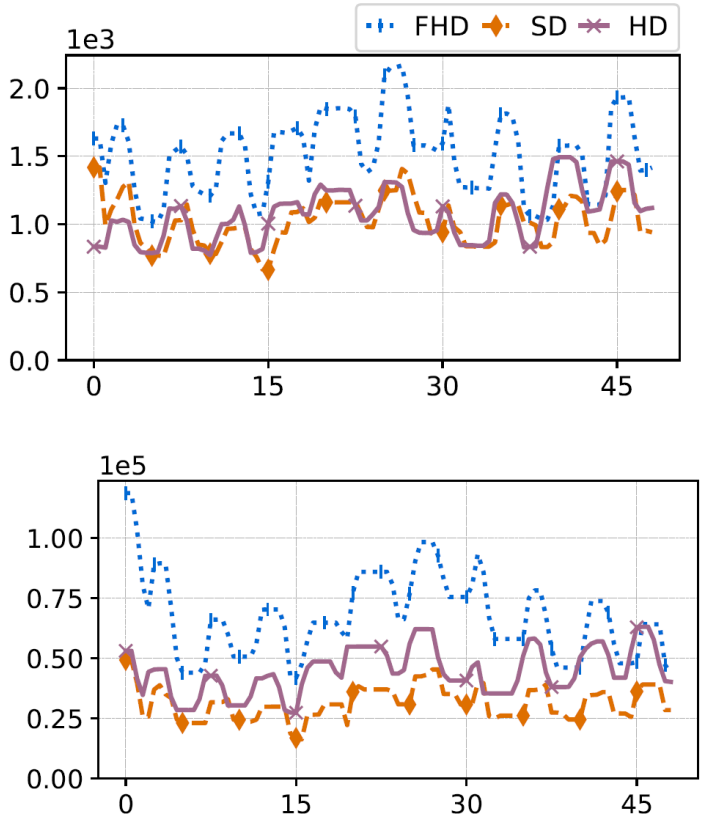
Fingerprinting Applications in the Wild



(a) Shopping Websites

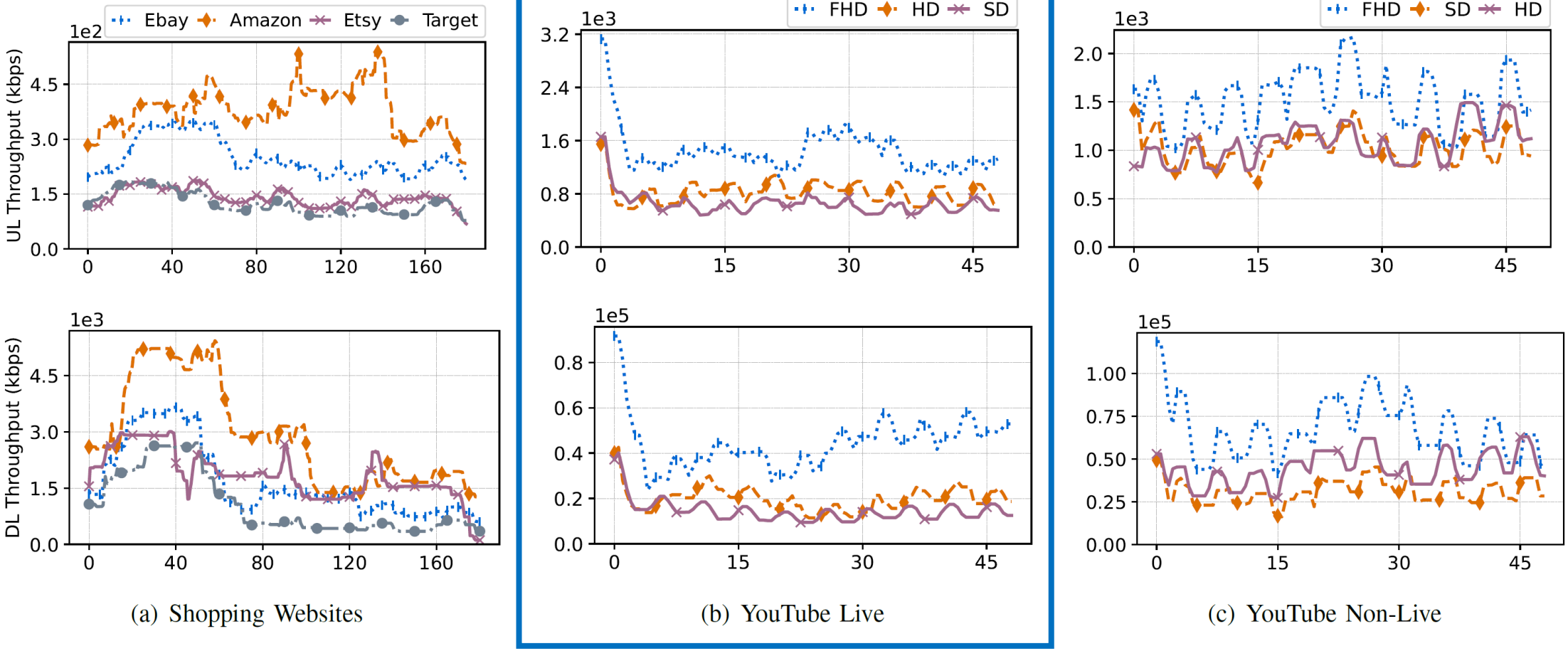


(b) YouTube Live



(c) YouTube Non-Live

Fingerprinting Applications in the Wild



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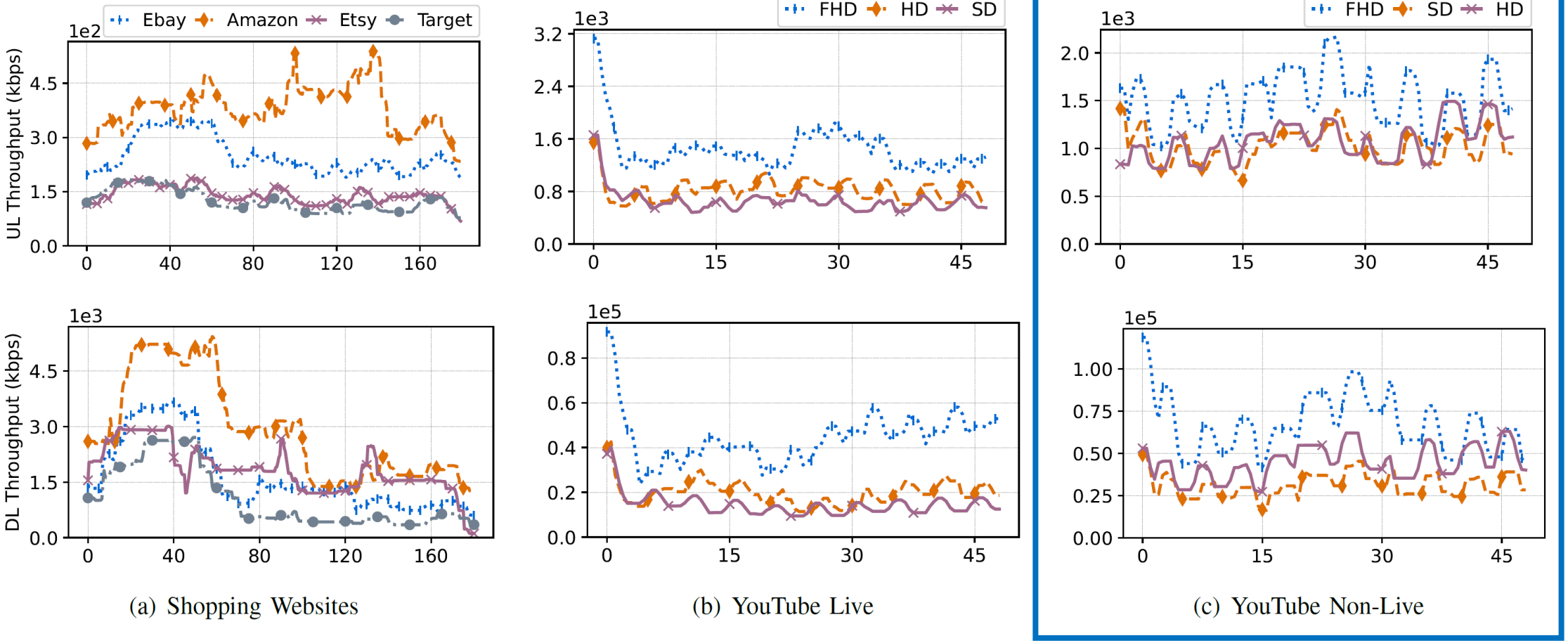

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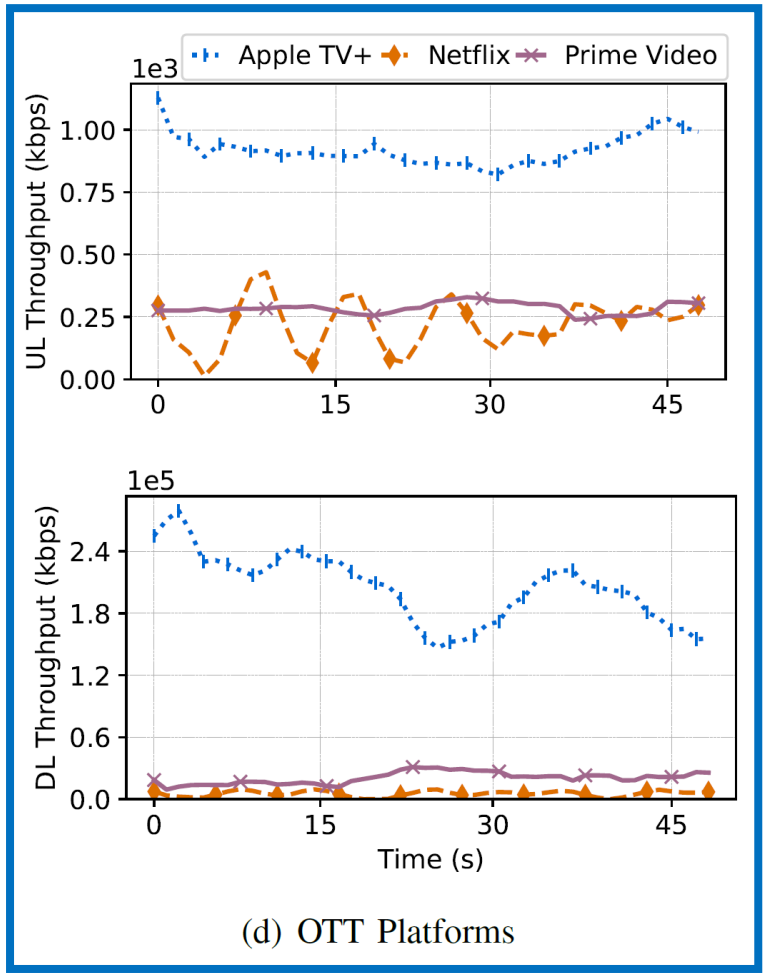
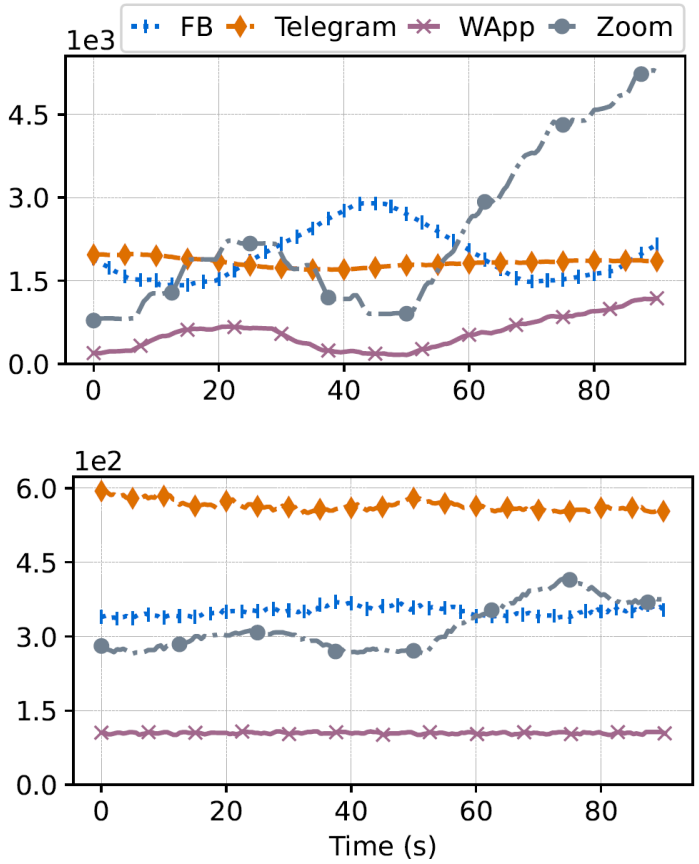
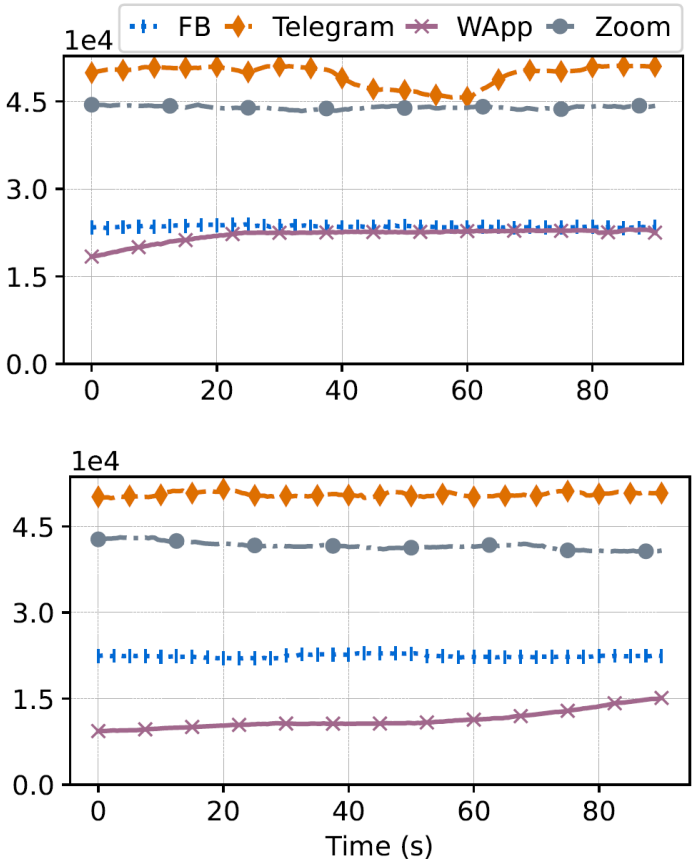


(d) OTT Platforms



(e) Voice Call



(f) Video Call

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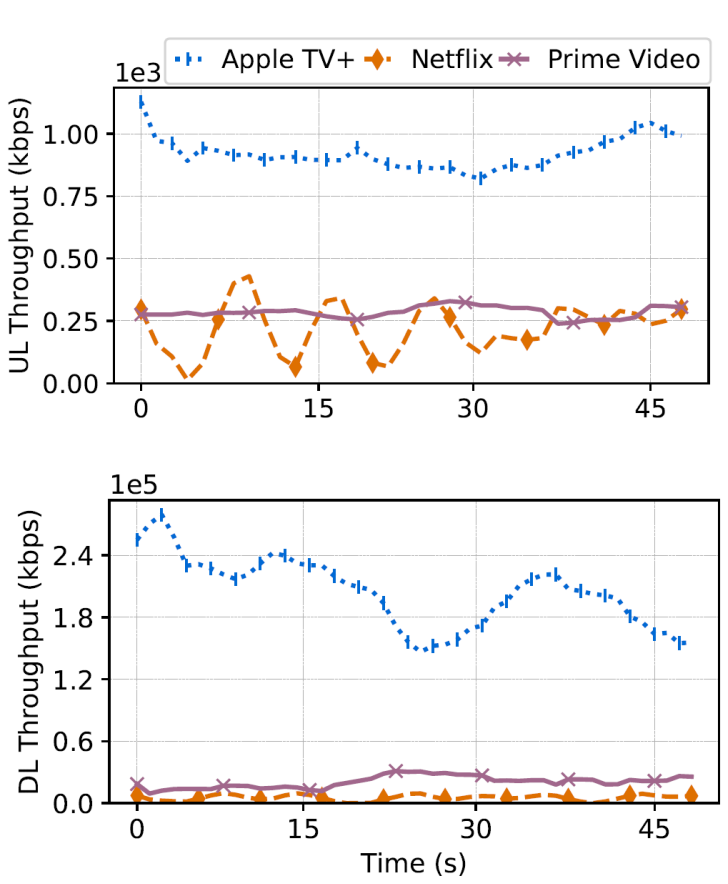

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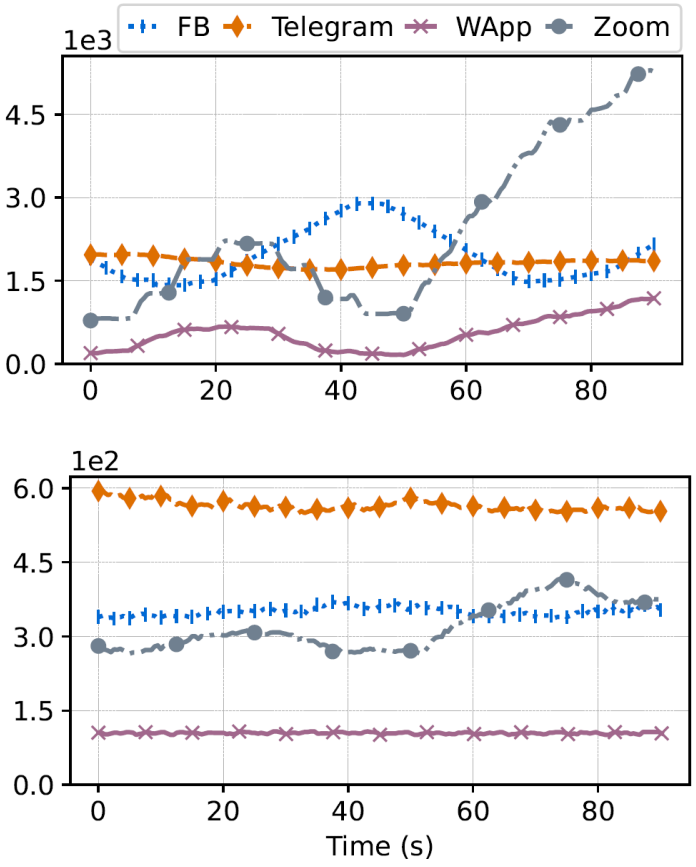

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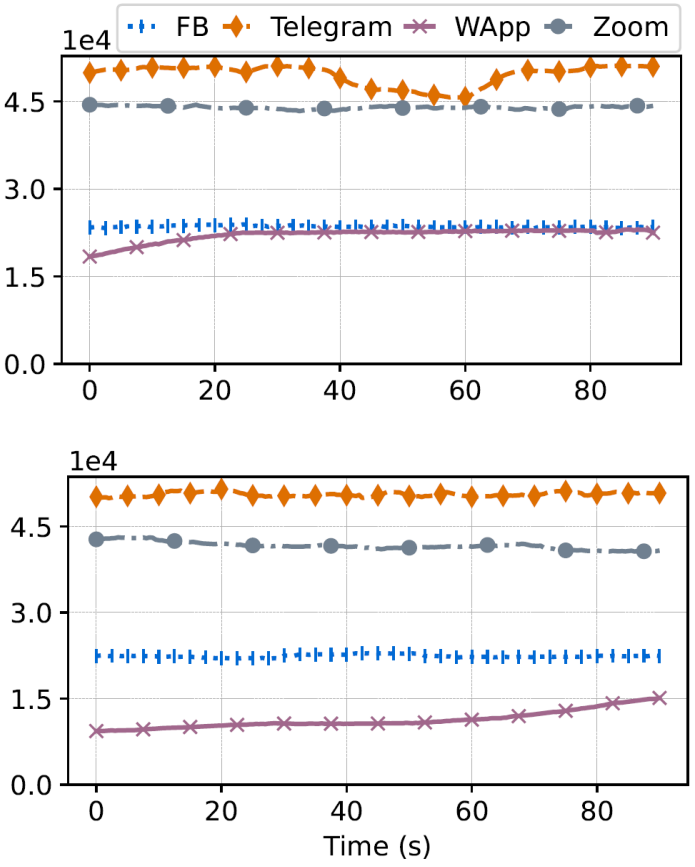

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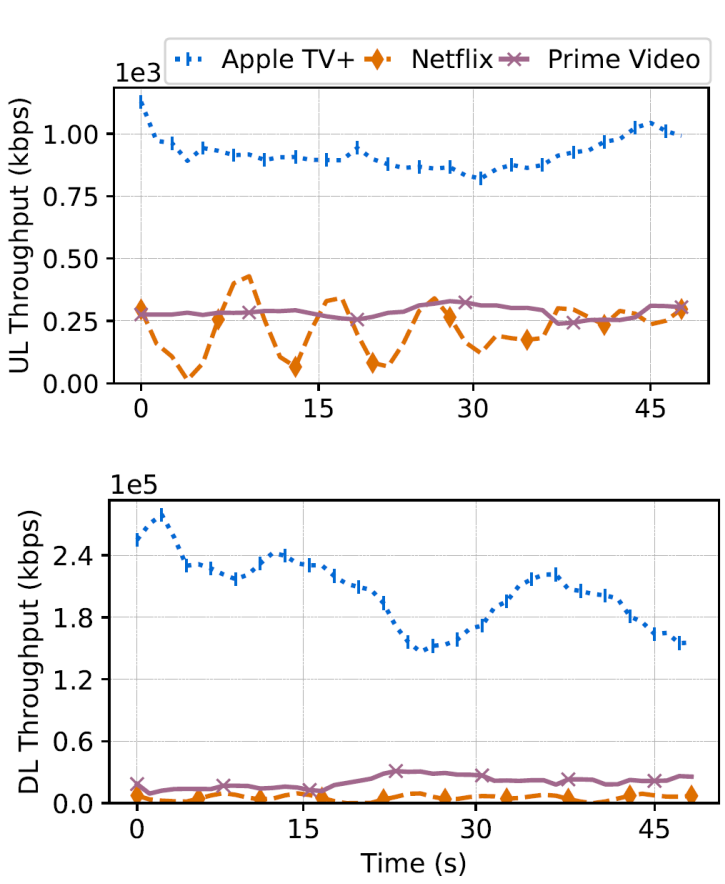

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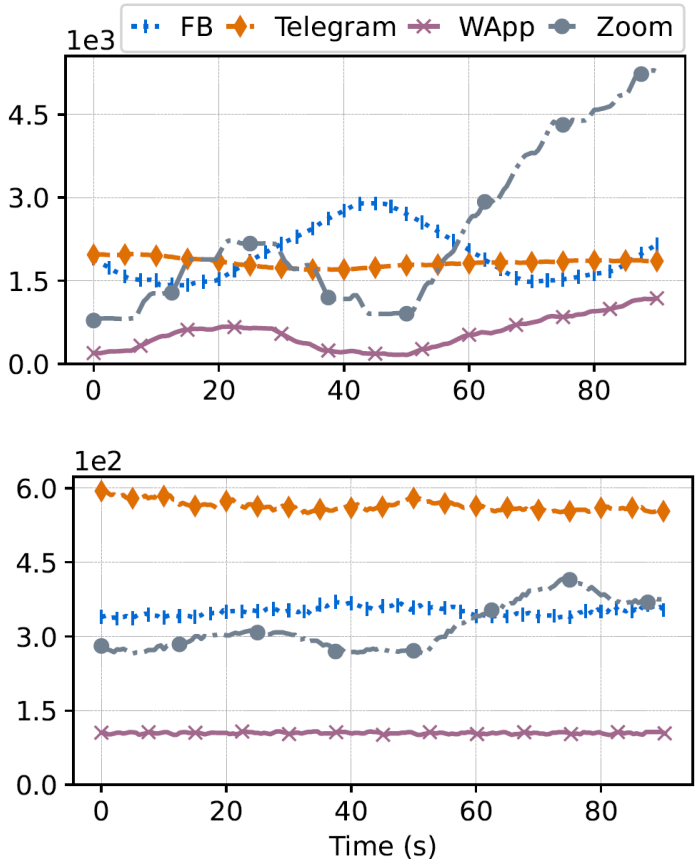

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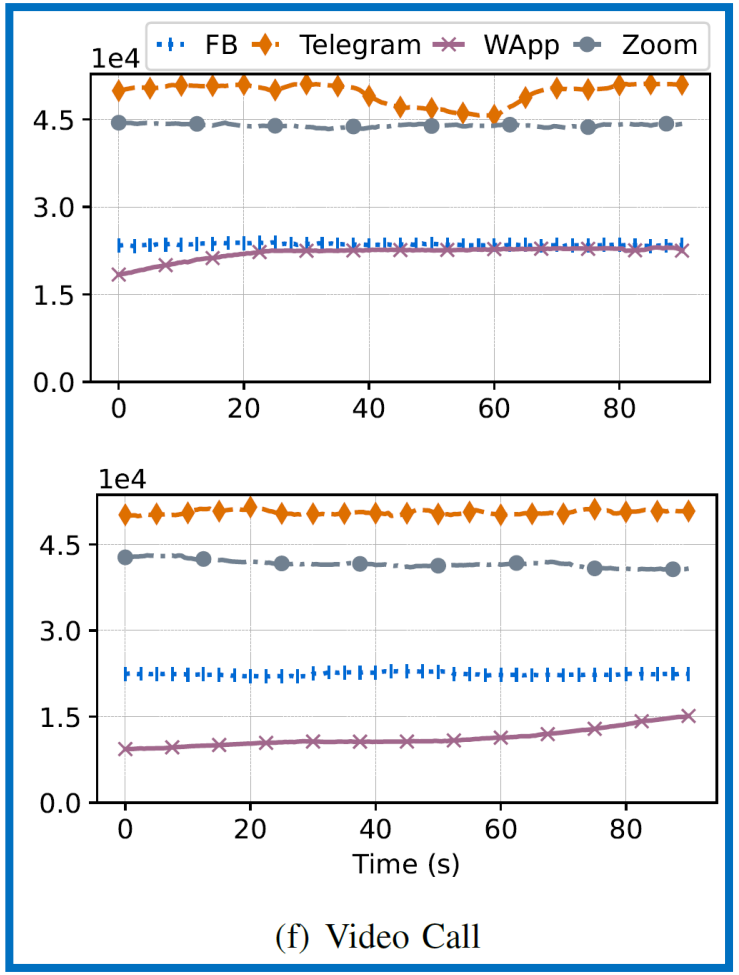

(f) Video Call

Application Classification

- **Random Forest** and **Extra Trees** classifiers for application and service category classification.
- We use similar hyperparameters and training setting for direct comparison.
- **Feature Generation:**
  - Min, Max, Mean, STD, Slope, Q1, and Q3

Models	Accuracy	Avg. Precision	Avg. Recall	Avg. F1-Score
Random Forest	94	93	94	93
Extra Trees	90	91	93	91

CONCLUSION

- We successfully fingerprinted various mobile applications in the wild using RRB traces.
- Our work highlighted the following insights:
  - Mobile applications generate **unique footprints** based on the number, types, and sizes of resources.
  - A correlation exists among the total resources, **RRB, and Wireshark** throughputs.
  - We can analyze both **continuous and cumulative** data to distinguish different types of applications.
- Our study aims to inform future design, implementation, and deployment decisions of 5G mobile networks and beyond.

Seeking internship opportunities!

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